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National Ignition Facility Small Optics Laser-Induced Damage and Photometry Measurements Program

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Abstract:

The National Ignition Facility will require upwards of 25,000 small optical components in its various beam conditioning and diagnostic packages. A quality control program designed to ensure that the elements meet the required specifications will test these optical elements. For many of the components, damage performance is one of the critical specifications, which will require state-of-the-art performance from the industry participants. A program was initiated to understand the current performance level of such optics. The results of this study as it pertains to laser-induced damage is shown. The use of ratio reflectometry is also addressed as the method of choice for photometry measurements on these industry supplied optics.

Key words: Optical coatings, qualification, specifications, laser-induced damage, photometry, ratio reflectometry

1. Introduction:

The National Ignition Facility will require several thousand meter-class optical components as well as several tens of thousands of small aperture (< 20 cm) components. The generic coatings required for these small optics are anti-reflection (AR) coatings, highly reflective (HR) coatings, and polarizers (POL) at 1053-nm (1w) and anti-reflection coatings (AR) and highly reflective (HR) coatings at 351-nm (3w).

Each optical element has specifications related to performance that will be evaluated by a quality assurance program. The coatings qualification program will be presented as well as generic results that will illustrate the state-of-the-art for laser damage resistant coatings across the industry. The laser damage test methodology used for this qualification program will be presented.

Ratio reflectometry has been chosen as the method for qualification of reflectance and transmittance specifications. The setup for this type of measurement and the results it can provide have significant value over the standard method of measurements with a spectrophotometer. The measurement is directly related to the use environment of the optic, can be made at single points or used to map out large-scale homogeneity, and is not limited in the size of the component which can be measured.

2. Laser Damage Measurements

Due to the localized nature of laser-induced damage on high quality optical components, test methods must be applied that can supply statistical data over large test areas. The test method that has been chosen at LLNL to achieve this is raster scanning. This method provides the statistical damage information needed for vendor evaluation, process control, and damage performance prediction.

2.1 Raster scan damage testing

The raster scanning method employs a millimeter scale guassian beam through which the optic is scanned. This is shown graphically in Fig. 1. After each pulse the gaussian beam position is translated a distance D(f%) in the x and y dimension, where D(f%) is the diameter of the beam at f% of the peak fluence. Since the laser is repetition rated at 10 hertz, the sample is in continuous motion at a velocity such that the optic has moved D(f%) by the time the next pulse arrives. D(90%) is typically 150-250 mm. For a standard test a 1-cm^2 area is scanned at an initial fluence specified by the requestor. For a 200 mm D(90%)beam size, 2500 sites are tested in that 1 cm^2 area. The fluence is then increased in 3 J/cm^2 increments until catastrophic failure is reached. This fluence increment was chosen in order to provide a well-resolved threshold value. It should be noted that the raster scanning process has the ability to condition certain optical materials (particularly some types of dielectric coatings and KDP crystals). The damage performance of the raster-scanned part should therefore be considered the conditioned performance. Unconditioned performance could potentially be lower.

There are two primary systems that will be used for the NIF small optics testing; Chameleon and the Automated Damage Test (ADT) facility. Chameleon is a 3 ns laser operating at 1064 nm. The ADT operates at 355 nm at a 7.5 ns pulselength. Both systems employ a scatter-based diagnostic for initial detection of damage. This diagnostic has a detection limit of 20-40 mm[(1)]. Damage is also observed by the operator between each fluence scan using a bright white light source. Operators can typically detect damage greater than 50 mm using this technique. Plasma emission from the sample surface may also be noted, but will not be used to determine the qualification fluence.

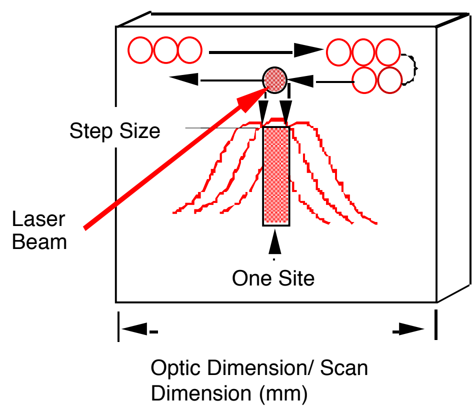


Fig. 1 Raster scanning entails translating the test area through a pulsed laser beam at a velocity such that the pulses are overlapped by a user defined amount.

3. NIF Small Optics Damage Qualification:

3.1 Damage testing procedure:

The systems and procedures for damage measurements at LLNL are well documented [(1-3)]. The small optics testing procedure is specific enough to warrant some further explanation. The raster scanning method is applied to allow for the testing of a significant amount of area. Sampling a large area increases the confidence in the optics performance rating.

3.2 Fluence determination

The damage performance is reported as a function of fluence in J/cm^2. The fluence is determined using a commercial beam profiling system and represents the peak fluence in the beam as viewed at zero degrees incidence. Further explanation of the fluence measurement can also be found in other references[(1)]. Note that the two damage test facilities have different pulse lengths. A simple equation has been defined to scale data by pulse length (Eq 1). The damage thresholds of bulk materials or bare surfaces can be scaled with pulse length by using a value of x equal to 0.5. Coatings are scaled with pulse length by a x equal to 0.35. These values were determined by experimentation at LLNL.

$$LIDT_{(pa)} = LIDT_{(plb)}\left(\frac{pa}{pb}\right)^{x} \qquad (1)$$

LIDT(pa) : Laser Induced Damage Threshold at pulse length a
LIDT(pb) : Laser Induced Damage Threshold at pulse length b

pa < pb :pulse lengths **x :** scaling factor

3.3 Determination of qualification level:

The damage data collected on vendor performance is grouped according to the component tested and the fluences it is qualified to transport. There are three qualification ratings for damage performance; 1) qualified, 2) probable, and 3) fail.

Qualified means that up to the specified fluence, the optic showed no signs of damage. Probable means that at the specified fluence one or more of the following occurs; 1) change in the scatter above the noise limit and verified to be damage by microscopy, 2) visible pinpoint damage observed by the operator which is less than 100 mm, does not grow, and occurs in less than 1% of the sites. The final category of fail is indicated if, at the specified fluence, one or more of the following occurs 1) pinpoint damage at more than 1% of the sites, 2) pinpoint damage larger than 100 mm or, 3) damage which indicates growth upon further illumination (considered to be catastrophic damage). The reason for the probable qualification is to provide the Small Optics Group with alternatives for high fluence components, with a quantified amount of risk.

Note that there is a +/- 15% error tolerance in the measurement of fluence on the damage test system. In the case where the sequential scan fluences are within 15% of each other, the qualification fluence should be that of the lower scan.

3.4 Example of vendor results and qualification:

A representative example of a recently tested sample is shown in Table 1. This generic example shows the qualification level at the right. The damage observation information is included so that the risk of using the optic in the probable range can be well understood. In this case at 24 J/cm^2 there were three 50 mm, damage sites which meets the criteria for probable. Also note in this example that the difference between the qualified fluence and the probable fluence is less than the 15% error of the fluence. In this case the lower fluence value of 21 J/cm^2 should be used as the maximum qualified fluence**.**

Table 1 Example of raster scan results and qualifications

Scan #	Fluence J/cm^2	Damage observations	NIF Small Optics Qualification
1	12.0	no visible damage	Qualified
2	15.0	no visible damage	Qualified
3	18.0	3 to 4 small plasmas, no visible damage	Qualified
4	21.0	3 to 6 small plasmas, no visible damage	Qualified
5	24.0	3, 50 mm damage sites	Probable
6	27.0	catastrophic damage	Failed

3.5 Damage performance evaluation of the industry

For the last several months, the NIF Small Optics program has been testing optics provided from many companies active in the optical coating field. A broad range of results has been found. Each sample has been evaluated using the qualification strategy outlined above. The results for the 1w optics is shown in Fig. 2 and for the 3w optics in Fig. 3. The samples are simply arranged in descending order based on their qualified fluence. These results will be used in the choice of possible suppliers of optical components based on their required damage specifications.

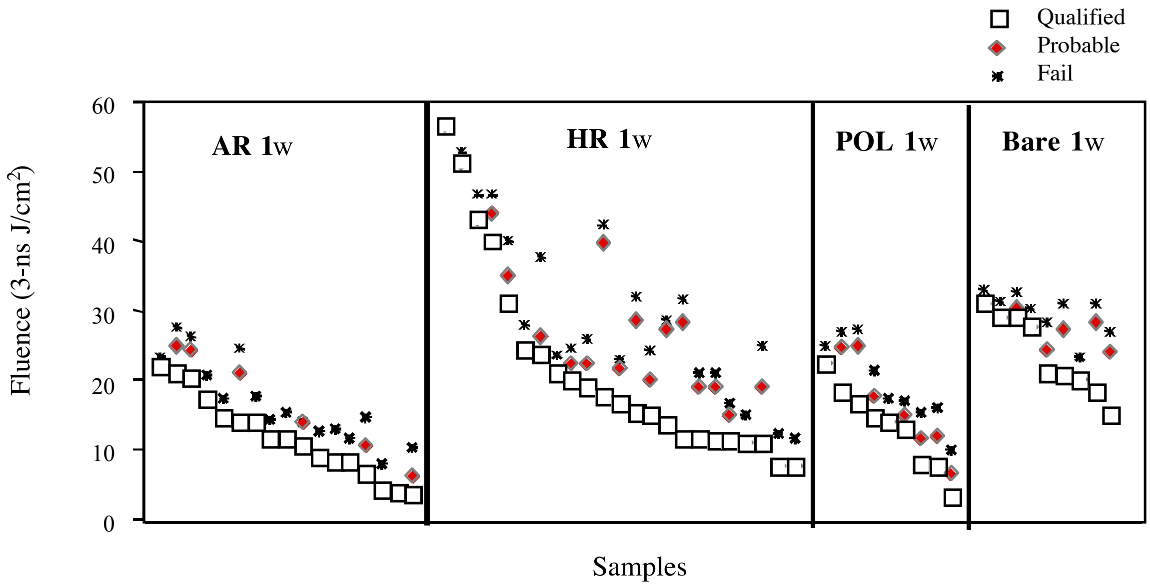


Fig. 2 Damage qualification results for optics operating at 1w. Displayed are the qualified, probable and fail fluence levels shown in descending order for each optic type.

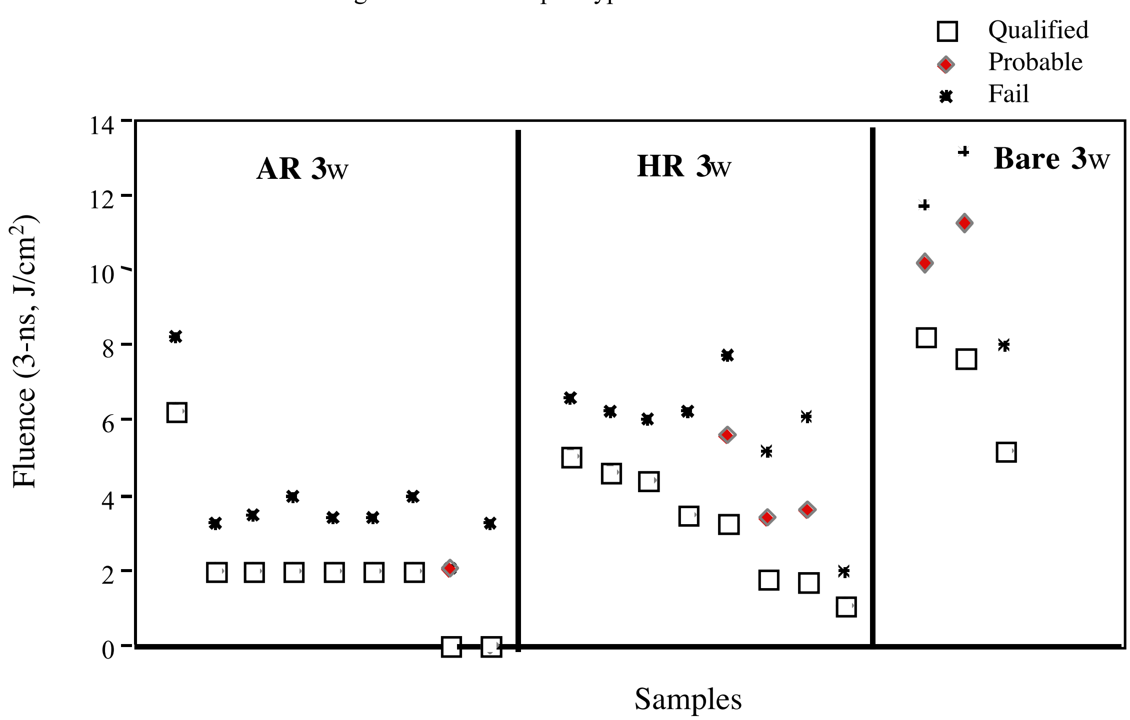


Fig. 3 Damage qualification results for optics operating at 3w. Displayed are the qualified, probable and fail fluence levels shown in descending order for each optic type.

4. Photometry for the NIF laser small-optics

Historically laser optics have been qualified for reflectivity specification conformance using a spectrophotometer. The problem with this instrument is that it typically has poor accuracy at both the high reflectivity end (>99%) and the low reflectivity end(<0.5%). In addition they have limited part size capability, handle polarization poorly, and the reflectivity attachments are poorly designed if they exist at all. Ironically most laser optics have reflectivity requirements at both extremes of reflectivity and many are used in polarized systems and used at angles other than normal incidence.

Ratio reflectometry has been used for some time by laser manufacturers, but has not become common at coating manufacturers. The device basically consists of a laser source at the wavelength of interest a beam splitter and two or more detectors that can be used to ratio the signals from each arm. The system then uses either the full beam energy or a reflectivity standard to compare to the part under test. Thus for an anti-reflection coating an uncoated substrate is typically used as the reference thus reducing the signal to noise by a significant amount to the just using the un-attenuated beam. This system lends itself to direct reflectivity measurements and to polarization specific measurements that are difficult to impossible on a typical spectrophotometer. An added benefit to a system like the NIF is that it is not limited in the size of optics that it can measure. Further this device will allow you to make a map of the reflectivity versus position on the part and thus uncover coating non-uniformity issues that a spectrophotometer simply can not identify, as it is an averaging instrument.

A ratio reflectometer can also be used to do angle sensitivity studies for optimizing polarizers or understanding their angular sensitivity. Suffice it to say that they are very versatile instruments and much better suited to assessing the usefulness and specifications of laser optics than a spectrophotometer.

4.1 Ratio reflectometer setups and example of its use

A typical ratio reflectometer setup using two detectors is shown in Fig. 4. A three detector ratio reflectometer setup that is being used for the NIF large optics reflectivity testing is shown in Fig. 5.

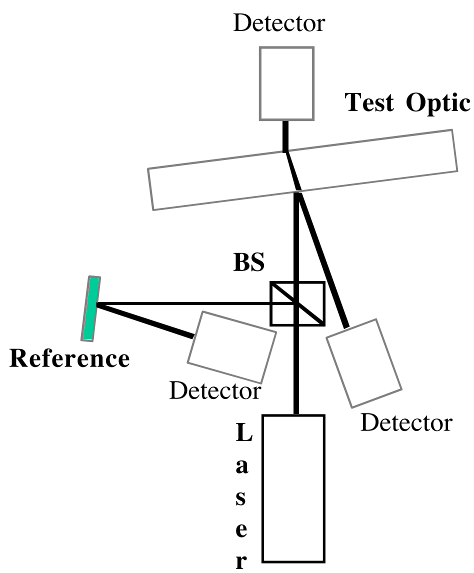


Fig. 4: The ratio reflectometer set up for two detectors measuring an antireflection coating with an optional third detector shown in gray.

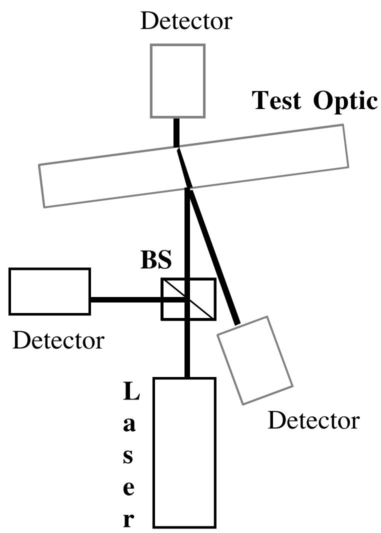
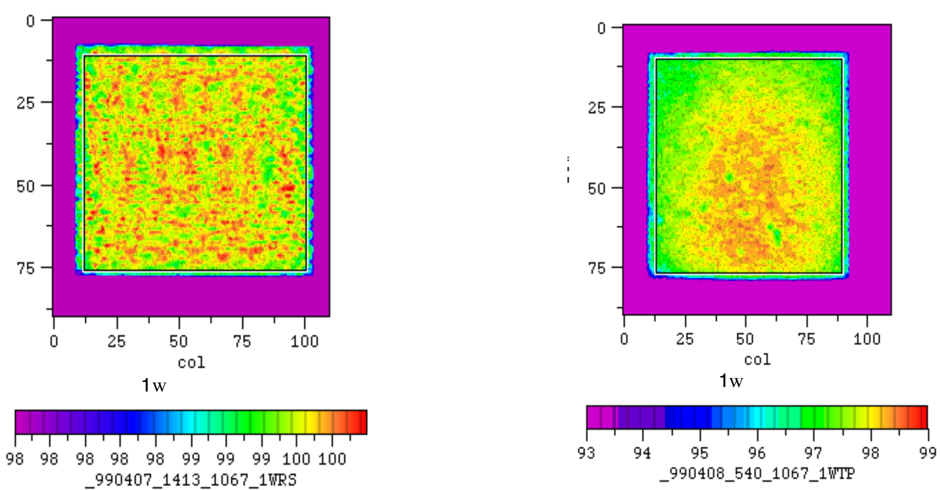


Fig. 5: A typical three detector ratio reflectometer that is self referencing is used for the NIF large optics photometry.

The measurements can be tested on a single point on the coating or scanned to form a surface map of reflectivity as shown in Fig 6. This is compared to a standard spectrophotometer trace for the same part shown in Fig. 7. One advantage of the spectrophotometer is that it provides reflectivity as a function of wavelength. The NIF small optics specifications have no requirement for such information.



Mean: 99.55
Max: 99.99
Min: 98.02

Mean: 97.79
Max: 98.82
Min: 94.92

Fig. 6: Typical ratio reflectometer maps for both “S” Polarization reflection (left) and “P” polarization transmission (right) for a thin film polarizer.

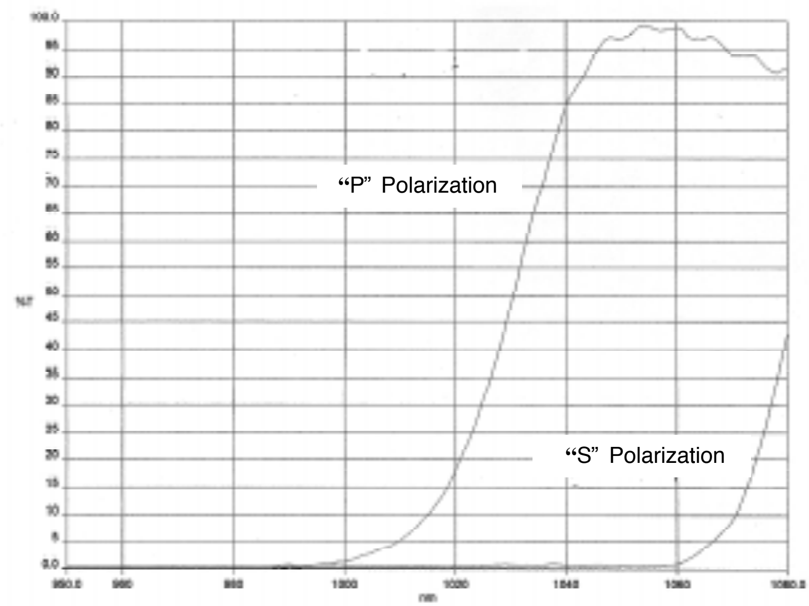


Fig. 7: A typical polarizer coating traces as produced by a spectrophotometer. Not the resolution difference compared to figure 3.

6. Conclusions:

Presented here is the plan for qualification of NIF small optics vendors based on laser damage performance. The raster scan test method was chosen in order to provide for testing of significant areas of the samples. The vendor performance at a given fluence is categorized as either “qualified”, “probable”, or “fail”, depending on the level of damage observed. This system allows a conservative measure of qualification level, while providing some insight into the risk associated with a change of the specifications. Vendors of small optic components have now been qualified for damage performance levels. This will allow them to be chosen as suppliers of components depending on their qualification level.

The usefulness of a ratio reflectometer and its relevance to measuring the reflectivity of laser optics is clear. Reflectivity at the wavelength desired in the appropriate polarization and at the correct angle of incidence can readily be acquired. The ability to measure large parts and to produce a surface map of the reflectivity of the part are tremendous benefits to a program like the NIF with a wide variety of sizes, from a few millimeters to meter class substrates.

Acknowledgements:

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